Engineering Experiment Station

NEW MEXICO STATE UNIVERSITY

ADVANCED STUDY OF VIDEO SIGNAL PROCESSING

IN LOW SIGNAL TO NOISE ENVIRONMENTS

By

Frank Carden
Alton Gilbert

A Semi-Annual Progress Report

Submitted to

NATIONAL AERONAUTICAL SPACE ADMINISTRATION
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NASA RESEARCH GRANT NGR-32-003-037

Electrical Engineering Department
Communication Research Group

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ABSTRACT

A generalized mathematical and computer model of the revised Apollo television system was developed and used to determine spectral compatibility with the overall Apollo Communication system. In particular the effects of the change to commercial television format from slow-scan black and white on the principal telemetering subcarriers was analyzed. Experimental data was obtained from MSC telemetry division confirming the analytical results.

INTRODUCTION

In changing from a sync burst synchronized slow-scan black and white system to a commercial type amplitude synchronized color television system, careful analysis was required to verify that the composite video spectrum would not interfere with the two principal telemetering subcarriers at 1.024 and 1.250 MHz.

The subcarrier at 1.024 MHz has either a 1.6 K bit data stream which is predetection filtered at the ground station with a 6 KHz bandwidth bandpass filter, or a 51.2 K bit data stream predetection filtered with a 180 KHz bandpass filter. The subcarrier at 1.250 MHz carries baseband (300 Hz - 3 KHz) analog voice and 4 biomedical subcarriers frequency modulated with IRIG frequencies.

A mathematical model similar to that used by Franks [1] was developed expressing the composite signal as a combination of the synchronizing signal and the appropriately blanked video process. Using a technique developed at New Mexico State University [2] the spectrum of the composite signal was determined by numerical two-dimensional Fourier analysis requiring lengthy computer runs for each video process. Typical processes were analyzed predicting that video interference levels were acceptable for a carrier narrow-band frequency modulated by the process, and that bit error rates for the telemetering subcarriers would not be affected appreciable by the changeover. Experimental work at the Manned Spacecraft Center in Houston [3] verified these results.

COMPOSITE VIDEO

The composite video waveform, $V_c(t)$, may be decomposed [1] into

$$V_c(t) = V(t)B_h(t)B_v(t) + S(t) \tag{1}$$

and S(t) may be decomposed into

$$S(t) = S_h(t)B_v(t) + S_{vf}(t)B_o(t) + S_{vc}(t) \tag{2}$$

where V(t) is the video process,

$B_h(t)$ is zero during horizontal retrace and one otherwise,

$B_v(t)$ is zero during vertical retrace and one otherwise,

$S_h(t)$ is a periodic train of pulses for horizontal synchronization,

$S_{vf}(t)$ is a periodic train of pulses formed by the serations on the top of the vertical sync pulses,

$S_{vc}(t)$ is a periodic train of vertical sync pulses with the serations removed,

$B_o(t)$ is one during vertical sync and zero otherwise.

Hence the composite video may be written as a combination of (1) and (2) as

$$V_c(t) = V'(t) + S_h(t)B_v(t) + S_{vf}(t)B_o(t) + S_{vc}(t) \qquad (3)$$

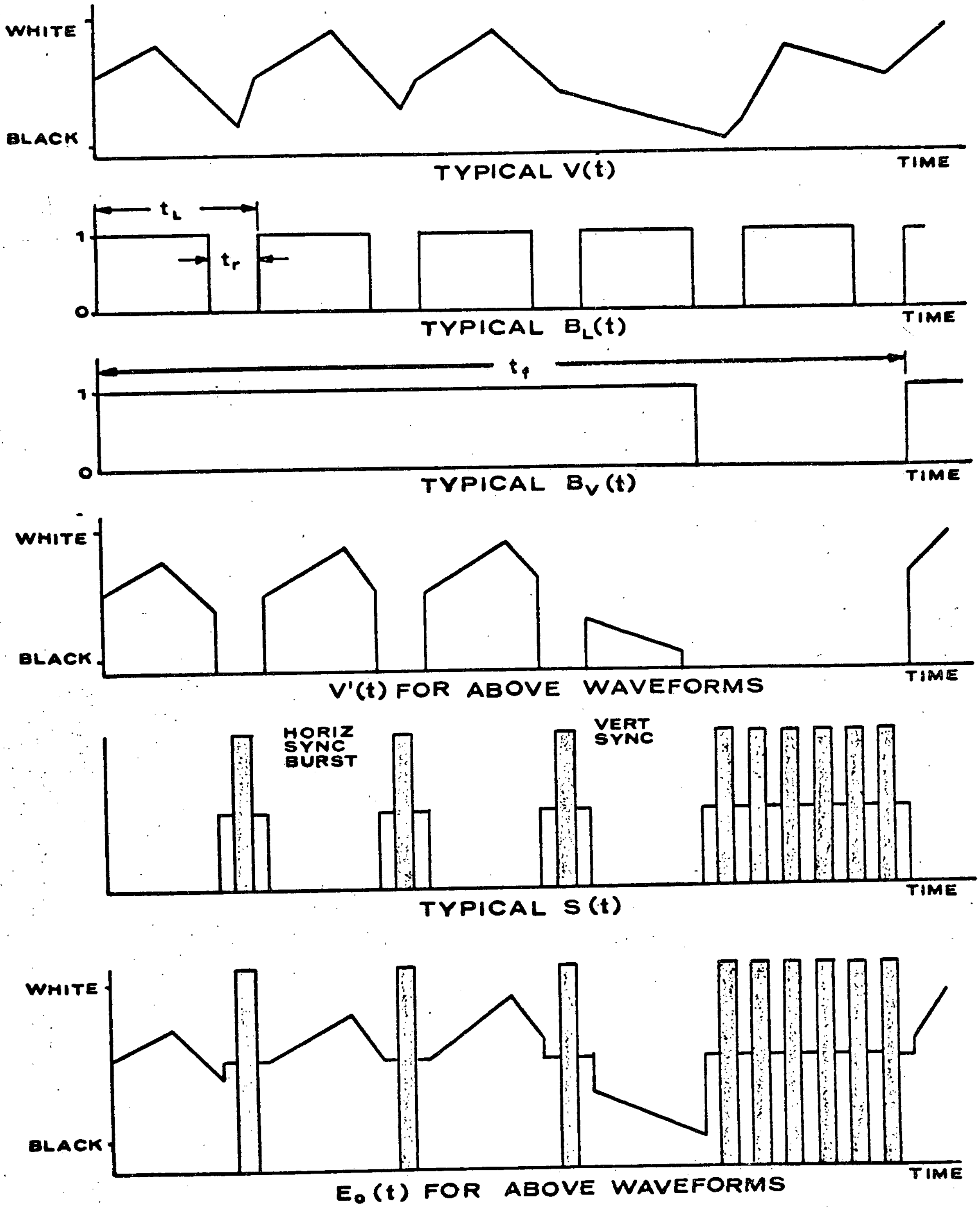
where $V'(c) = V(t)B_h(t)B_v(t)$. A time domain representation of the composite video signal is given in Figure 1. The evaluation of the composite video spectrum requires the evaluation of Equation 3 term by term.

$S_{vc}(t)$ Term

For commercial format television this term is a pulse train of 1100 μ sec pulses spaced 16,667 μ sec apart. Computing the Fourier series of such a train yields frequency components at multiples of 60 Hz, with no significant component above 15 KHz. Hence this term will not effect the required bandwidth, and is of no interest in the problem at hand.

$S_{vf}(t)B_o(t)$ Term

In order to evaluate this term the detail on the top of the vertical sync pulse, $S_{vf}(t)$, was approximated by a pulse train of 3.5 μ sec pulses spaced 31.75 μ sec apart. Further, since $B_o(t)$ is very low in frequency content the spectrum of the product is approximately the spectrum of $S_{vf}(t)$, since the blanking function is a square wave with very high duty cycle. $S_{vf}(t)$ was Fourier transformed and the resulting power spectrum was numerically evaluated. This term is of little importance in the analysis, however, since the power in the term is less than 0.3% of the power of the composite video. Power in a 6 KHz bandwidth about 1.024 MHz is on the order of $10^{-8}E_o^2$, where E_o is the maximum voltage level of the composite video, and is therefore negligible.



TIME DOMAIN REPRESENTATION
OF A COMPOSITE VIDEO SIGNAL

FIGURE 1

$S_h(t)B_v(t)$ Term

Again we have $B_v(t)$ a low frequency term and hence the spectrum of the product can be approximated by the spectrum of $S_h(t)$. Using Fourier analysis of the horizontal sync signal it was found that there was only one component within a 6 KHz bandwidth about the 1.024 MHz subcarrier, and the power of that component, P_{ih_1}, is

$$P_{ih_1} = (1.682 \times 10^{-5})E_o^2 \tag{4}$$

The power in the 180 KHz bandwidth about 1.024 MHz was found to be

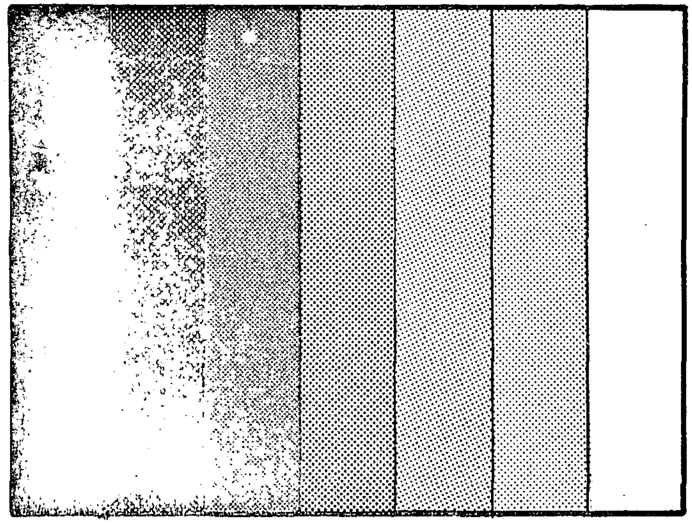
$$P_{ih_2} = 1.75 \times 10^{-4}E_o^2. \tag{5}$$

The power in this restricted bandwidth above 1 MHz is therefore very small relative to the total power in the $S_h(t)B_v(t)$ term, and a cumulative power calculation shows that 99% of the total power for this sync signal lies below 1 MHz.

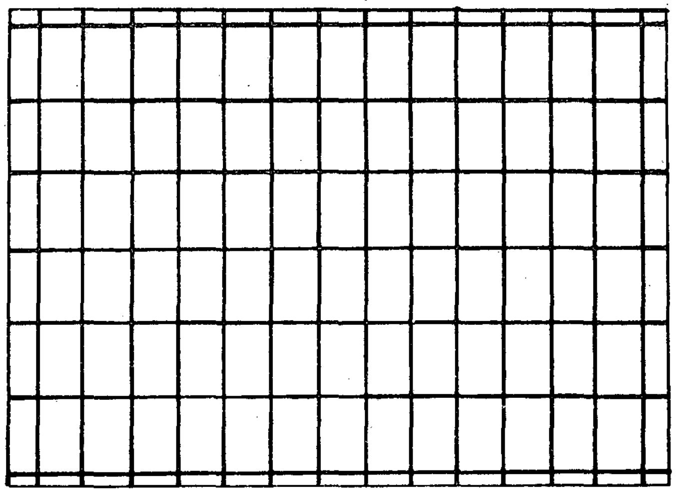
$V(t)B_h(t)B_v(t)$ Term

This is the only term that is a function of the video process. This term was evaluated for the two test patterns shows in Figure 2, and these processes were evaluated by the method given in [2].

The results of the evaluation of the Gray scale are shown in Figure 3. Figure 3a shows the course structive of the power spectrum, where C is normalized power in dB, out to 1.5 MHz, and Figure 3b shows a 6 KHz bandwidth detail about 1.024 MHz. The power in this bandwidth can be calculated by adding the 101 components in this region, and the result is



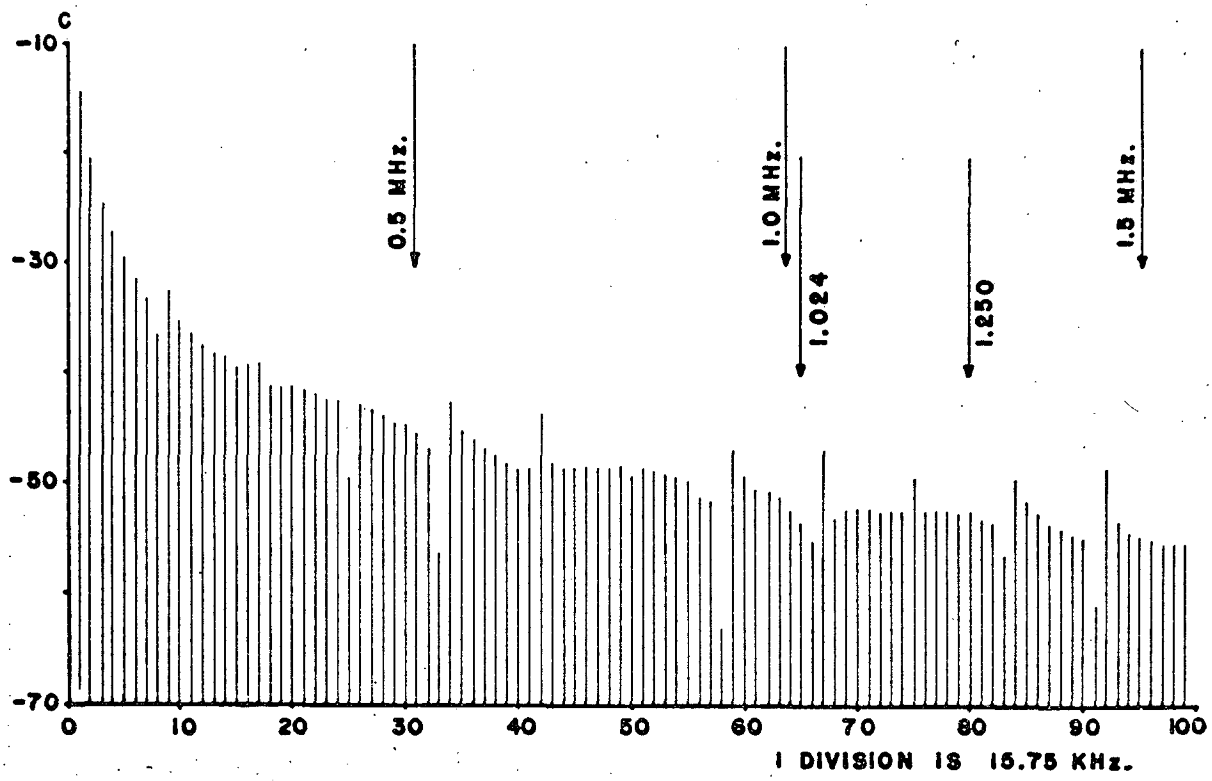
GRAY TEST PATTERN



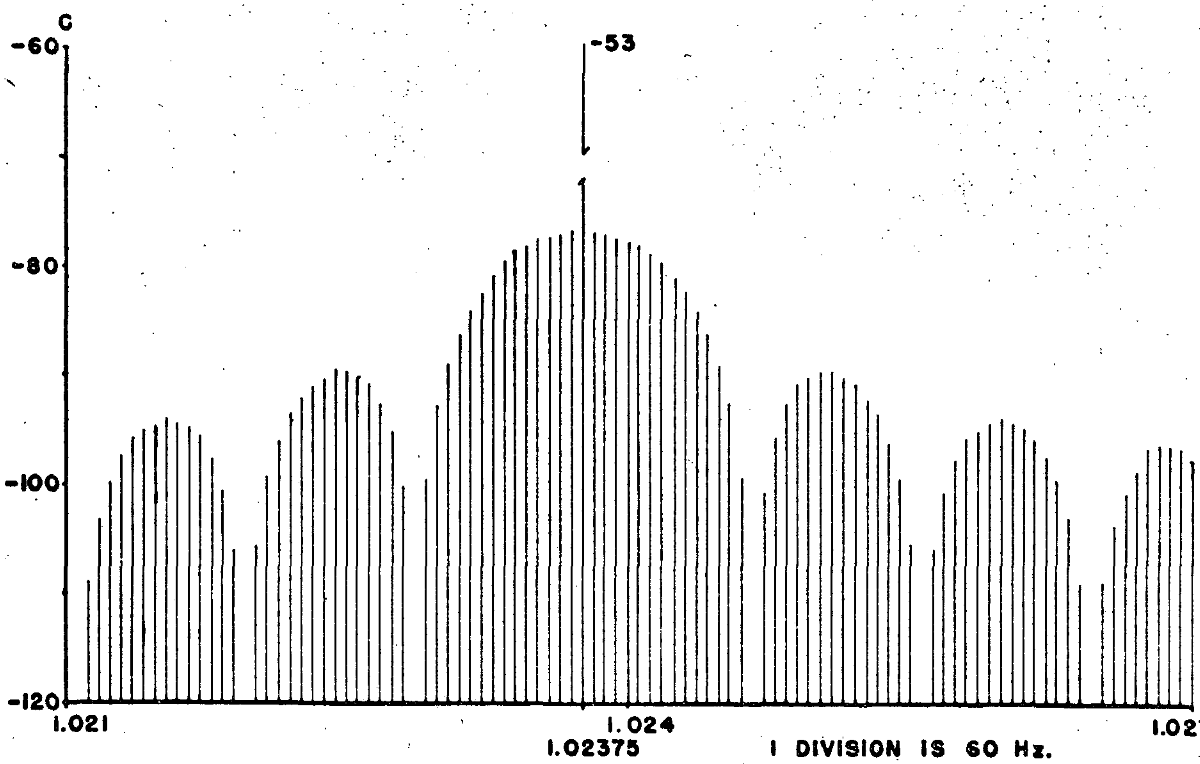
GRATE PATTERN

NASA TEST PATTERN

FIGURE 2



a. Coarse



b. Detail

FIGURE 3.
GRAY PATTERN

$$P_{iv_1} = 4.786 \times 10^{-6} E_0^2 \qquad \text{(Gray)(6)}$$

From the course spectrum it can be seen that the components in this region are all approximately equal, so the power in the 180 KHz bandwidth about 1.024 MHz is approximately 30 times the power in the 6 KHz bandwidth, or

$$P_{iv_2} = 1.436 \times 10^{-4} E_o^2 \qquad \text{(Gray)(7)}$$

Similarly the power spectrum in the Grate pattern (NASA pattern) is shown in Figure 4. Figure 4a shows the course structure of the power spectrum out to 1.5 MHz, and Figure 4b shows the detail for a 6 KHz bandwidth about 1.024 MHz. The power in a 6 KHz bandwidth is

$$P_{iv_1} = 3.353 \times 10^{-6} E_0^2 \qquad \text{(Grate)(8)}$$

and in the 180 KHz bandwidth it is approximately 30 times P_{iv_1}, i.e.,

$$P_{iv_2} = 1.006 \times 10^{-4} E_o^2 \qquad \text{(Grate)(9)}$$

SUBCARRIER TO INTERFERENCE POWER RATIO CALCULATIONS

Combining the above information the subcarrier power to television interference power interference ratio can be calculated for the two subcarrier bandwidths and for the two test patterns. Denoting the peak amplitude of the subcarrier by E_1, then

$$P_c = E_1^2/_2 \,. \qquad (10)$$

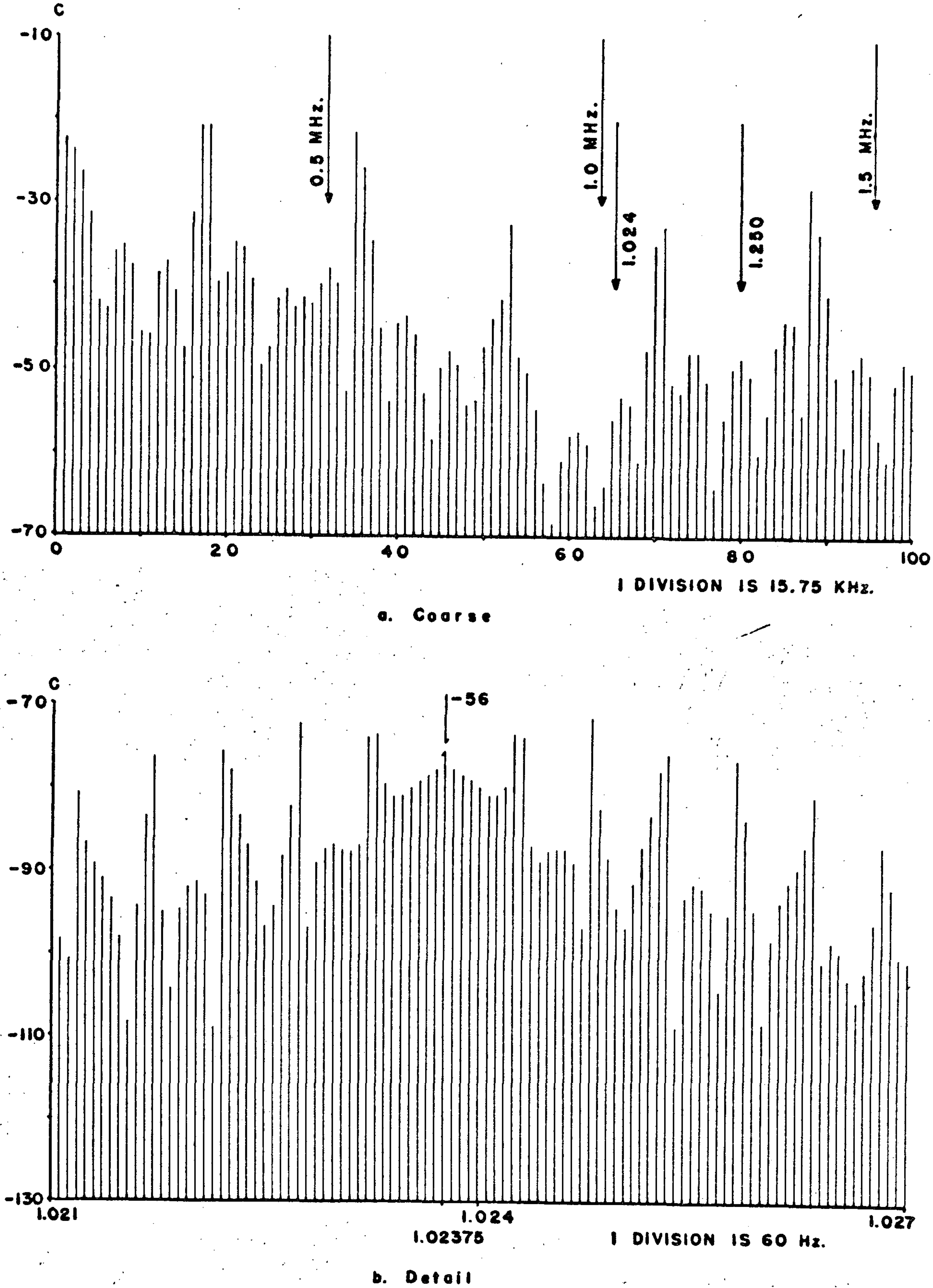


FIGURE 4.
GRATE PATTERN

The interference power is

$$P_i = P_{ih} + P_{iv} \tag{11}$$

Hence the subcarrier to interference power ratio, CIR, can be calculated by

$$CIR = \frac{P_c}{P_i} \tag{12}$$

and for the 6 KHz bandwidth about 1.024 MHz

$$CIR_1 = 2.31 \times 10^4 \left(\frac{E_1}{E_0}\right)^2 \quad \text{(Gray)} \tag{13}$$

$$CIR_1 = 2.48 \times 10^4 \left(\frac{E_1}{E_0}\right)^2 \quad \text{(Grate)} \tag{14}$$

and for the 180 KHz bandwidth about 1.024 MHz

$$CIR_2 = 1.57 \times 10^3 \left(\frac{E_1}{E_0}\right)^2 \quad \text{(Gray)} \tag{15}$$

$$CIR_2 = 1.81 \times 10^3 \left(\frac{E_1}{E_0}\right)^2 \quad \text{(Grate)} \tag{16}$$

So then it can be seen that for E_1 and E_0 of the same order to magnitude CIR_1 is approximately 40 dB, and CIR_2 is approximately 30 dB.

Since the CIR in both of these cases is very great, it was anticipated that the bit error rate in the telemetering subcarriers would be due principally to noise, and that the interference from television would have no noticeable effect, since the total modulating signal consisted of baseband composite television and the two principal telemetering subcarriers all frequency modulated onto the S-band carrier.

EXPERIMENTAL RESULTS

At the Manned Spacecraft Center in Houston tests were conducted to determine the effects of using the commercial format color television on the bit error rates of the principal telemetering subcarriers. The results of these tests showed that for a television Δf as high as 1.3 MHz the presence of television caused less than an order of magnitude difference for the bit error rate. Since pre-modulation filtering of 600 KHz did not subjectively degrade the picture quality, this represents a modulation index of over 2 and is about 10 times the normal figure of 0.2 given as an upper bound for narrow-band F.M. [4]. Consequently the experimental results showed that even much larger modulation indices than those normally accepted as narrow-band F.M. still did not increase the bit error rate by an order of magnitude. The bit error rates for no television and television with Δf of 1.3 MHz are shown graphically in Figure 5. Upon examination it can be seen that the performance of the system is degraded by only about 1 dB at a bit error rate of 1×10^{-4}. This degradation is attributed to VCO dynamic range limitations and system non-linearities as well as phase lock loop demodulation limitation.

CONCLUSION

Models were developed and analysis performed to determine the effect of changing from slow-scan black and white television to commercial formatted sequential color television on the Apollo missions. Particular

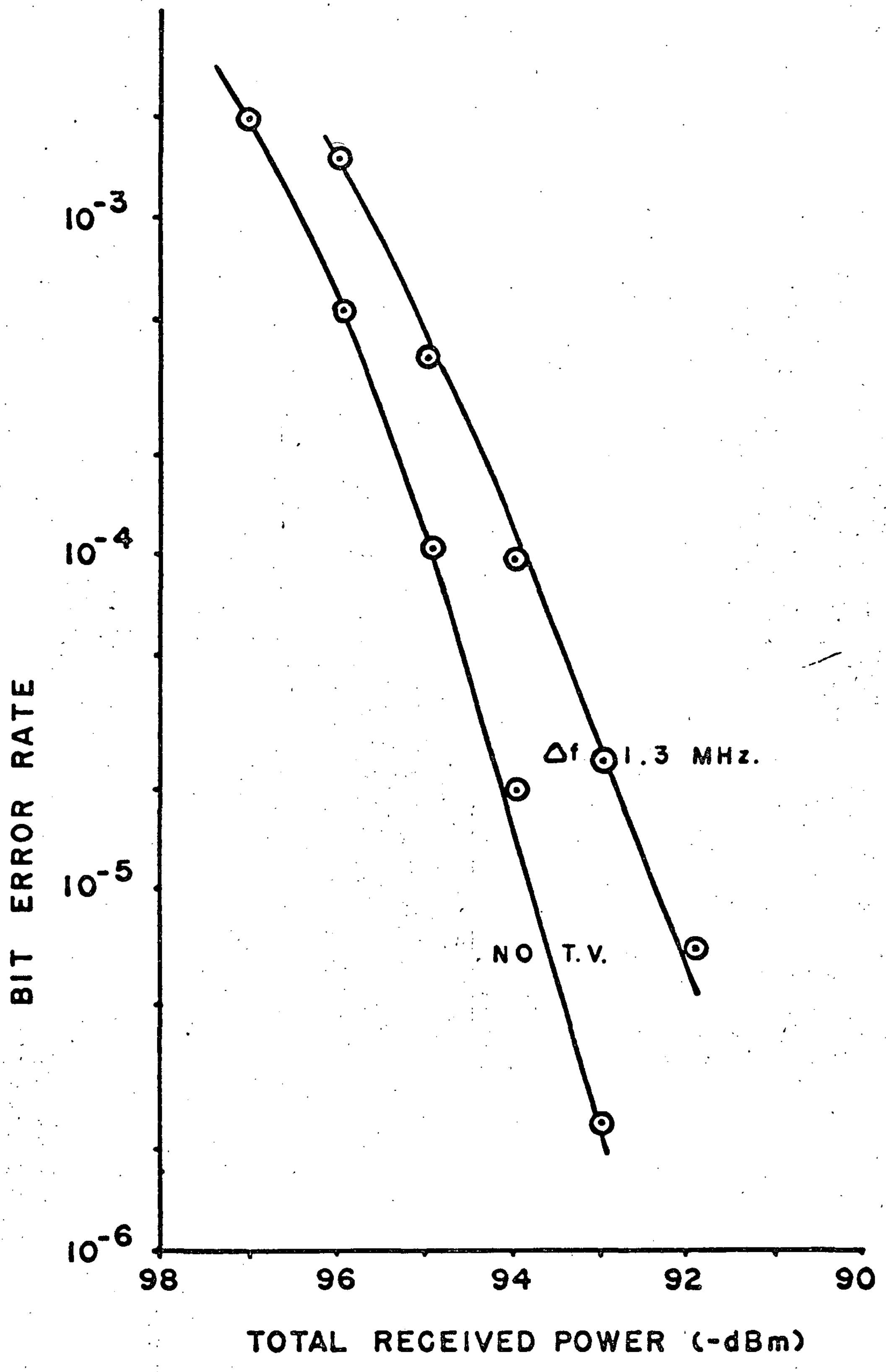

BIT ERROR RATE
10-3
10-4
10-5
10-6
Δf 1.3 MHz.
NO T.V.
98
96
94
92
90
TOTAL RECEIVED POWER (-dBm)

FIGURE 5

attention was given to the subcarrier to interference power ratios for the principal subcarriers. It was predicted that the television signal would not significantly interfere with the subcarriers. It was then shown that the bit error rates remained within an order of magnitude of the rates for no television present with modulation indices as high as 2.0. Final recommendation by the testing facility that a Δf of 1.5 MHz be used represented a wide-band frequency modulation with acceptable bit error rates down to a total received power of -100.6 dBm.

APPENDIX - Television Lines, Fields, and Frames

A black-and-white television broadcast signal for a single line scan consists of a synchronizing pulse to lock the receiver's scanning beam to the broadcast scanning frequency, a blanking period that provides time for the scanning beam to return from the previous scan, and the video brightness signal that reproduces the brightness level of the scene being scanned. A complete frame (picture) of 525 lines is produced in 1/30 second, but, to reduce flicker, each frame actually consists of two interlaced fields, one field being the even numbered lines and the next field the odd lines. Thus, the standard TV vertical frequency is 60 fields per second. [To conserve bandwidth, the Westinghouse black-and-white TV camera used for the moon-landing telecast transmits video information to earth at 10 frames per second (no interlacing) and 320 lines. From this information, signal processing at the ground station synthesizes a standard interlaced 60-field-per-second signal for broadcasting.]

The NTSC (National Television System Committee) standard color signal is fully compatible with the standard monochrome broadcast signal even though the color signal contains three different kinds of video information. A color camera used three camera tubes to produce three separate video signals, one for each primary color. These color signals are electronically matrixed to provide two signals for broadcasting: the luminance signal is synthesized from the three primary color signals--59 percent green, 30 percent red, and 11 percent blue--bit for all practical purposes is identical to a monochrome signal; the chrominance signal, also derived from the three primary color signals, is superimposed on the luminance signal and is both phase and amplitude modulated. The luminance and chrominance signals are reprocessed at the color television receiver to reproduce the three primary color signals. But to a black-and-white receiver, the chrominance signal frequency (3.58 MHz) is such that signals from consecutive fields are 180 degrees out of phase and the chrominance signal is blanked out. [Actually, this cancellation is due to the choice of the subcarrier frequency of 3.579545 MHz, which is an odd multiple of one half the line frequency. The line frequency chosen is 15734.264 Hz, and (15734.364/2) x 455 = 3.579545 MHz. Since there are 252.5 lines per field, 15734.264 ÷ 252.5 = 59.94 fields per second, the standard vertical frequency for color.]

The mechanical field-sequential scheme used for the Apollo color camera uses a color wheel to insert color filters before a single camera tube so that red, blue, and green fields are transmitted sequentially at the standard color field rate (59.94 fields/second). Thus, a full-color field must be synthesized from three separate single-color fields. This is accomplished at the ground station with a magnetic disk recorder of the type used for instant replay. The color fields, transmitted from the camera in serial form, are switched and recorded on six separate tracks on a magnetic disk (red, blue, green, red, blue, green). Six tracks are used rather than three to provide time for erasure between recordings. Switching logic and delay circuits are used to develop synchronized red, blue, and green output fields in parallel. Since red, blue, and green fields are coming into the recorder at 59.94 fields per second in serial form, and are commutated out at 59.94 fields per second in parallel, each field transmitted from the camera must be used three times, yielding an effective color field rate of 20 fields per second. The three parallel output signals from the recorder are fed to a color encoder where they are converted to the standard NTSC signal for broadcasting.

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